

APPLICATION  
FOR  
UNITED STATES LETTERS PATENT

TITLE: CONTINUOUS SLOPED PHASE EDGE ARCHITECTURE  
FABRICATION TECHNIQUE USING ELECTRON OR  
OPTICAL BEAM BLUR FOR SINGLE PHASE SHIFT  
MASK RET

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**CONTINUOUS SLOPED PHASE EDGE  
ARCHITECTURE FABRICATION TECHNIQUE  
USING ELECTRON OR OPTICAL BEAM BLUR FOR  
SINGLE PHASE SHIFT MASK RET**

**BACKGROUND**

**[0001]** A phase shift mask (PSM) may include alternating clear regions (which may be designated as zero (0) and  $\pi$  ( $\pi$ ) regions) with different step heights. The different step heights cause the light to be phase-shifted  $180^\circ$  between the two regions. As a consequence, the light from the clear zero region interferes destructively with the light diffracted from the adjacent  $\pi$  region, causing an unexposed (dark) area on the photoresist layer.

**[0002]** "Phase conflict" is a potential problem in PSM technology. Phase conflict arises from unintentionally joining two regions that transmit light with opposite phases. Destructive interference of the light from these two regions may create artificial features on the wafer (e.g., unwanted lines).

**[0003]** Phase conflict may be avoided by using a double exposure/two mask method. In a first exposure, a PSM is used to image a pattern, which may include undesired features caused by phase conflict. In a second exposure, a binary (e.g., chrome-on-glass) "trim" mask is used to clear

the undesired features. However, the addition of the second (trim mask) exposure may introduce overlay errors, reduce flexibility of physical design, and increase cycle time, labor, and production costs. These problems may worsen as the process margins of photolithography decrease and the pattern densities of integrated circuits increase.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0004] Figure 1 is a block diagram of a photolithography system.

[0005] Figure 2 is a sectional view of a phase shift mask (PSM).

[0006] Figure 3A is a sectional view of a PSM having an abrupt boundary between two phase shift regions.

[0007] Figure 3B is a sectional view of a PSM having a sloped boundary between two phase shift regions.

[0008] Figures 4A-4D show a process flow for producing a PSM including a sloped phase edge architecture.

**DETAILED DESCRIPTION**

[0009] Figure 1 shows an optical lithography system 100. Light from an illumination source 105 is transferred to a patterned mask 110 by an illumination system 115. Light

passes through the mask and into the entrance pupil of an imaging system 120. The resulting pattern is imaged onto a photoresist covered wafer 125 by a lens 130 in the imaging system.

[0010] The mask 110 may be a phase shift mask (PSM). The quality of an imaged pattern produced with a typical binary mask may be degraded by light from clear areas on the mask diffracting into regions that ideally would be completely dark. The nominally dark region may have light diffracted into it from the adjacent nominally bright regions. A PSM may be used to reduce such diffraction and improve image contrast on the wafer.

[0011] Figure 2 shows an exemplary PSM 200. In the PSM, alternating clear regions (which may be designated as zero (0) regions 210 and pi ( $\pi$ ) regions 205) may have different step heights which cause the light to be phase-shifted 180° (90°/270° phase steps may also be used). As a consequence, the light from the clear zero region interferes destructively with the light diffracted from the adjacent pi region, causing an unexposed (dark) area on the photoresist layer. This may improve image contrast on the wafer.

[0012] PSMs may be fabricated using photolithography techniques. A glass substrate is coated with a layer of

photoresist material. The photoresist may be exposed with a pattern on a mask to define phase shifted regions in the glass substrate. Depending on the tone of the photoresist (i.e., positive or negative), the exposed areas of the photoresist will be made either be more soluble (positive) or less soluble (negative). The more soluble areas of the photoresist are then removed in a development process, leaving portions of the substrate exposed. The exposed surfaces (and the remaining resist) may then be etched to form features with step heights corresponding to a phase shift at the wavelength used for the lithography tool in which the mask will be used (e.g., 193 nm).

**[0013]** "Phase conflict" is a potential problem in PSM technology. Phase conflict arises from unintentionally joining two regions that transmit light with opposite phases. Destructive interference of the light from these two regions may create artificial features on wafer (e.g., unwanted lines).

**[0014]** Phase conflict may be avoided by using a double exposure/two mask technique. In a first exposure, a PSM is used to image a pattern, which may include undesired features caused by phase conflict. In a second exposure, a binary (e.g., chrome-on-glass) "trim" mask is used to clear the undesired features. However, the addition of the

second (trim mask) exposure may introduce overlay errors, reduce flexibility of physical design, and increase cycle time, labor, and production costs.

**[0015]** Phase conflict may be caused by the abruptness in the boundary (step) 302 between two adjacent phase shift regions 304 (0), 306 ( $\pi$ ), as shown in Figure 3A. In an embodiment, phase conflict may be avoided by lengthening a lateral distance 308 over which the phase transition occurs to form a continuous sloped phase edge between adjacent phase shift regions, as shown in Figure 3B. The gradual transition may prevent unwanted features from printing at the boundaries between phase shift regions. The lateral distance of the boundary may be on the order of the wavelength of light used in the lithography tool in which the mask will be used (e.g., order of  $10^2$  nm).

**[0016]** A continuous sloped phase edge between phase shift regions may be produced during the fabrication of the PSM using a "controlled blur" imaging technique. The imaging system used for mask lithography (e.g., optical or electron beam) may include a defocus control to control the amount of defocus at the imaging plane. The imaging system may be operated in a deliberate "out-of-focus" condition, creating a sloped dose gradient in the exposed resist at the boundary between exposed and unexposed regions.

[0017] Figures 4A-4D show a process flow for producing a PSM including a sloped phase edge architecture. An exposure dose 400 maybe applied to a resistance material 402 on a glass substrate 404, as shown in Figure 4A. The "slope" of this dose gradient can be adjusted by the degree of defocus applied to the electron beam. The "slope" of the dose gradient may be selected based on the value required to manufacture the slope in the etched glass. The dose gradient creates a slope 406 in the resist 402 under suitable resist development conditions, as shown in Figures 4B and 4C. When the resist 402 is etched, the slope 406 is imposed on the final glass profile 408, as shown in Figure 4D. In the embodiment shown in Figures 4A-4D, the glass/resist etch rate is approximately 1:1 such that the glass and resist edge at approximately the same rate. However, other glass/resist etch rates may produce satisfactory results.

[0018] In an embodiment, the degree of defocus may be adjusted for individual shot exposures allowing the dose gradient to vary over a large range. For example, the degree of defocus may be adjusted for different figures in the mask. In addition, the defocus may be asymmetric, enabling the dose gradient to be, e.g., steep for vertical edges while gradual for horizontal edges.

[0019] The use of sloped phase-edge architecture in the PSM may eliminate the need for a second exposure with a trim mask. Accordingly, alignment problems associated with the second exposure may be avoided. Also, the single exposure process may be more compatible with high speed manufacturing.

[0020] Another technique for generating a gradual phase transition is to provide a stepped boundary (e.g.,  $0^\circ/90^\circ/270^\circ$  or  $0^\circ/60^\circ/120^\circ/180^\circ$ ). However, such stepped boundaries may result in printing out-of-focus and may require a more complex manufacturing process. The embodiments described above may produce a relatively smooth and gradual phase transition which may avoid these problems.

[0021] A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.